A high resolution, "multi-energy" soft X-ray (ME-SXR) diagnostic is being developed for the NSTX edge plasma. The system will measure with spatial resolution of ≤ 1 cm and with ~10 kHz bandwidth the XUV and SXR emission from the outer NSTX regions, including the pedestal, and will serve for studies of edge particle and electron transport, of ELM dynamics, and other edge phenomena. The system comprises five tangential AXUV diode arrays, viewing the plasma between 0.5<r/a<1.1 through filters of varying composition and thicknesses, including a bare diode array. The filters provide a coarse sub-sampling of the XUV-SXR spectrum and will enable measuring changes in the electron temperature, density, and impurity concentration, on fast time scales. The obtain the electron temperature and the particle density the emissivity profiles are modeled using a coronal atomic model and a look-up table algorithm. In addition, a Transmission Grating imaging spectrometer is used to constrain the impurity fractions in this model. Supported by DOE contract no. DE-AC02-09CH11466.

Linearization of elements contributing to x-ray emission allows separation of T_e, n_e, and impurity concentrations by using the differences between filtered measurements

SXR emissivity, E_f, is a function of density and impurity response weighted by concentration

$$E_f\left(n_e, T_e, c\right) = n_e^2 \sum_i c_i R_{f,i}$$

2nd order expansion adds additional terms, including 'cross-term' dependence on change in temperature and density

$$\Delta E_f = \frac{\partial E_f}{\partial n_e}\Delta n_e + \frac{\partial^2 E_f}{\partial n_e^2}\frac{\Delta n_e^2}{2} + \frac{\partial E_f}{\partial T_e}\Delta T_e + \frac{\partial^2 E_f}{\partial T_e^2}\frac{T_e^2}{2} + \frac{\partial^2 E_f}{\partial n_e \partial T_e}\Delta n_e \Delta T_e$$

linear terms
quadratic terms
cross-term

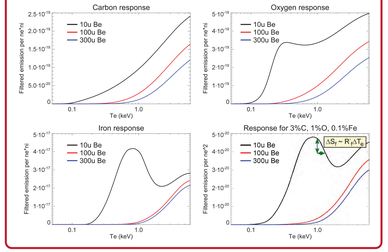
Change in relative emissivity depends also on curvature of filtered response function

$$\frac{\Delta E_f}{E_f} = \frac{2\Delta n_e}{n_e} + \frac{\Delta n_e^2}{n_e^2} + \frac{\sum_i c_i R'_{f,i}}{\sum_i c_i R_{f,i}}\Delta T_e + \frac{\sum_i c_i R''_{f,i}}{\sum_i c_i R_{f,i}}\frac{\Delta T_e^2}{2} + \frac{2}{n_e}\frac{\sum_i c_i R'_{f,i}}{\sum_i c_i R_{f,i}}\Delta n_e \Delta T_e$$

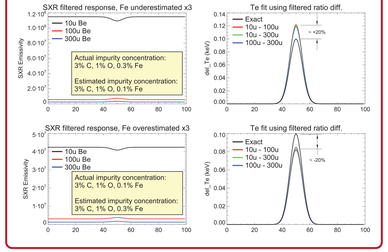
Difference of relative emissivities removes 1st and 2nd order terms, but leaves dependence on density from 'cross-term,' solve for T_e using quadratic equation

$$\frac{\Delta E_{f1}}{E_{f1}} - \frac{\Delta E_{f2}}{E_{f2}} = \left(\frac{\sum_i c_i R'_{f1,i}}{\sum_i c_i R_{f1,i}} - \frac{\sum_i c_i R'_{f2,i}}{\sum_i c_i R_{f2,i}}\right)\left(1 + \frac{2\Delta n_e}{n_e}\right)\Delta T_e + \left(\frac{\sum_i c_i R''_{f1,i}}{\sum_i c_i R_{f1,i}} - \frac{\sum_i c_i R''_{f2,i}}{\sum_i c_i R_{f2,i}}\right)\frac{\Delta T_e^2}{2}$$

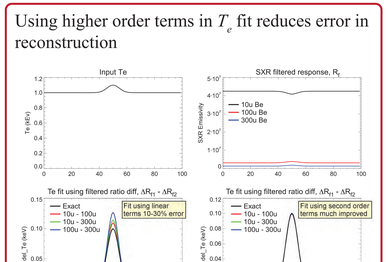
Filtered response tables $R_i(T_e)$ used to calculate x-ray signals and fit fast T_e measurements



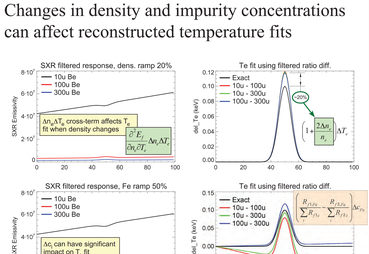
Temperature fits relatively insensitive to uncertainties in impurity concentrations



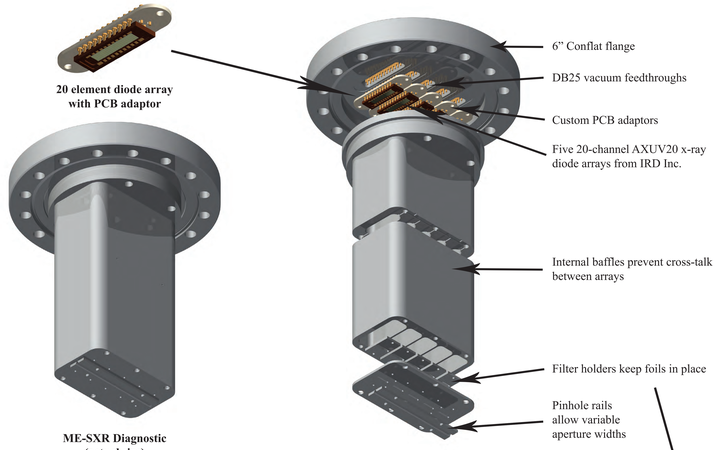
Using higher order terms in T_e fit reduces error in reconstruction



Changes in density and impurity concentrations can affect reconstructed temperature fits

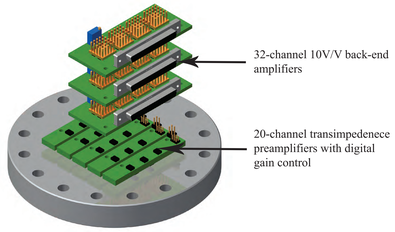


The Multi-Energy Soft-X-Ray Array is a novel compact diagnostic that provides T_e, n_e, and impurity profile information with high spatial resolution (<1 cm) and fast time response (>10 kHz)



Gains	Bandwidth
25 kΩ	300 kHz
100 kΩ	120 kHz
500 kΩ	50 kHz
1 MΩ	35 kHz
2 MΩ	26 kHz
5 MΩ	16 kHz
10 MΩ	11 kHz
20 MΩ	6 kHz

Preamplifier gains are digitally controlled, with higher gains having providing less bandwidth

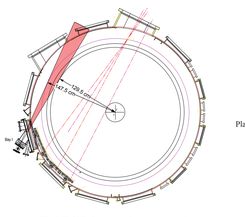


Electronics on back side of vacuum flange (actual size)

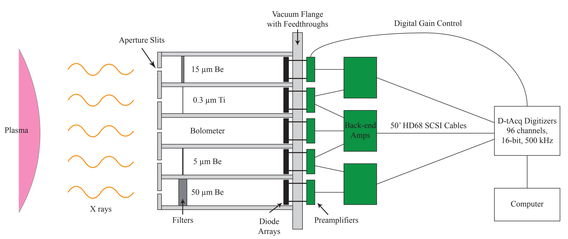
Each diode array looks through a different filter:

Bolometer (no filter)
0.3 μm Ti
5 μm Be
15 μm Be
50 μm Be

NSTX Top View

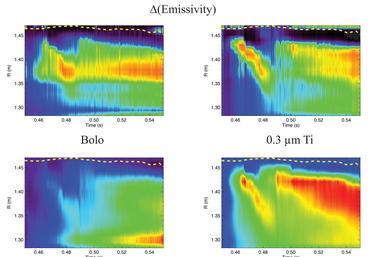


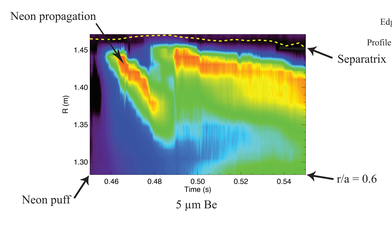
The ME-SXR diagnostic has a tangential view of the plasma edge (0.6 < r/a 1.1)



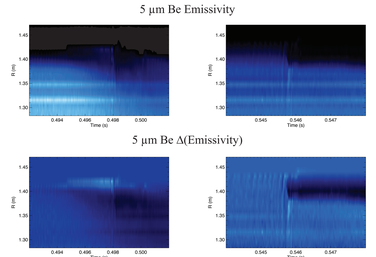
Initial data reveal dynamic processes in the plasma edge and are consistent with modeling

The high spatial and time resolution of the ME-SXR system allows the tracking of neon injection in the edge of NSTX plasmas.

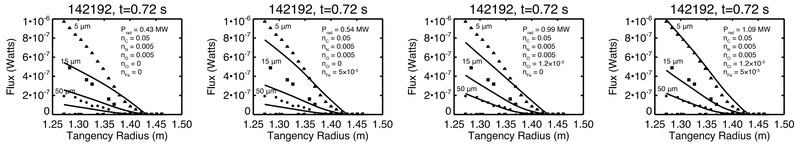




The novel capabilities of the ME-SXR system allow an examination of the various mechanisms behind the different ELM phenomena in NSTX.



Multi-energy x-ray intensity profiles are consistent with impurity response modeling with concentrations derived from spectroscopic diagnostics (see Kumar *et al.*, BP9.00087)



Low-Z impurities (C, N, O) only account for about half of the measured line-integrated x-ray intensities and total radiated power (P_{rad}~1 MW). n_e is measured by CHERS, and the ratios n_i/n_e and n_{Ti}/n_e are obtained from spectroscopy.

Spectroscopic diagnostics also measure small amounts of Fe, though not enough to account for the high-energy flux measured with the 50 μm Be array.

Spectroscopy also shows strong Cl lines. A Cl concentration of 1.2×10^{-3} increases the model P_{rad} and 50 μm Be intensity to the expected values.

With both the Fe and Cl included in the model, the simulated x-ray intensity closely matches measurement. Missing data points are due to a digitizer malfunction.

ME-SXR measurements will contribute to FY11 DOE JOULE milestone for pedestal structure characterization

Near-term Diagnostic Plans:

- Precision spatial and absolute calibration of detectors
- Measurement of filter thickness and transmission
- Next generation of electronics for better noise immunity

Diagnostic Plans for NSTX-U:

- Vacuum-compatible pre-amplifiers for in-vessel arrays
- Poloidal ultra-fast (~5MHz) dual-energy arrays

Near-term Physics Plans:

- Edge impurity transport and accumulation studies
- Fast profile dynamics of ELM evolution (n_e, T_e)
- Fast/slow edge MHD (RWMs, islands, disruptions)

Physics Plans for NSTX-U:

- Multiple toroidal detectors for measurements of toroidally asymmetric phenomena
- T_e, n_e poloidal measurements of MHD and fast-ion modes